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(54) **PHOTOVOLTAIC MODULE MANUFACTURE**

(75) Inventors: **Markus Gloeckler**, Perrysburg, OH (US); **Imran Khan**, Perrysburg, OH (US)

(73) Assignee: **First Solar, Inc.**, Perrysburg, OH (US)

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(51) **Int. Cl.**
H01L 21/00 (2006.01)

(52) **U.S. Cl.**
USPC **438/64**; 438/88; 438/795

(58) **Field of Classification Search** .... None
See application file for complete search history.

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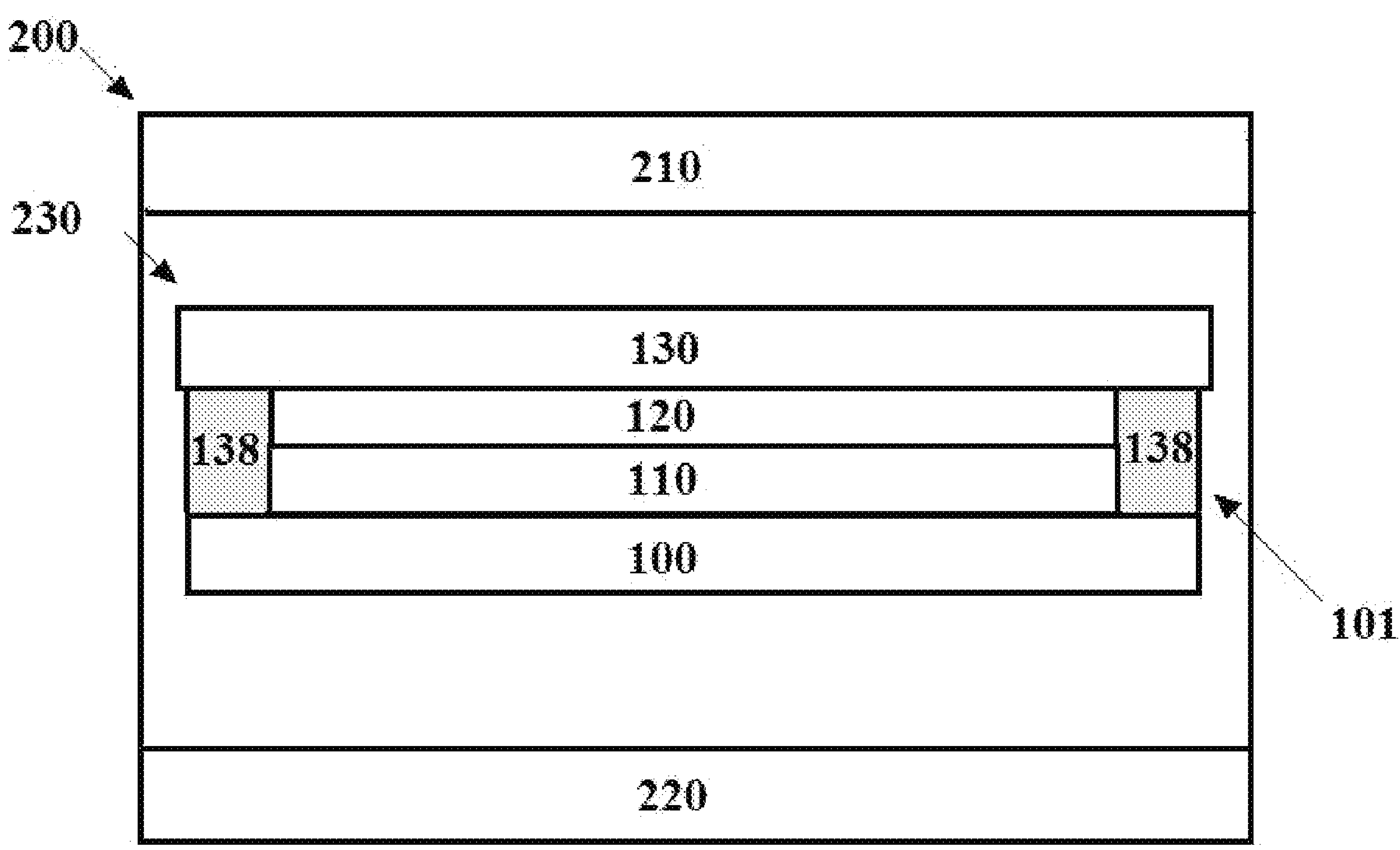
Primary Examiner — Scott B Geyer
(74) *Attorney, Agent, or Firm* — Dickstein Shapiro LLP

(57) **ABSTRACT**

A method for manufacturing a photovoltaic module including a laminating step.

17 Claims, 6 Drawing Sheets



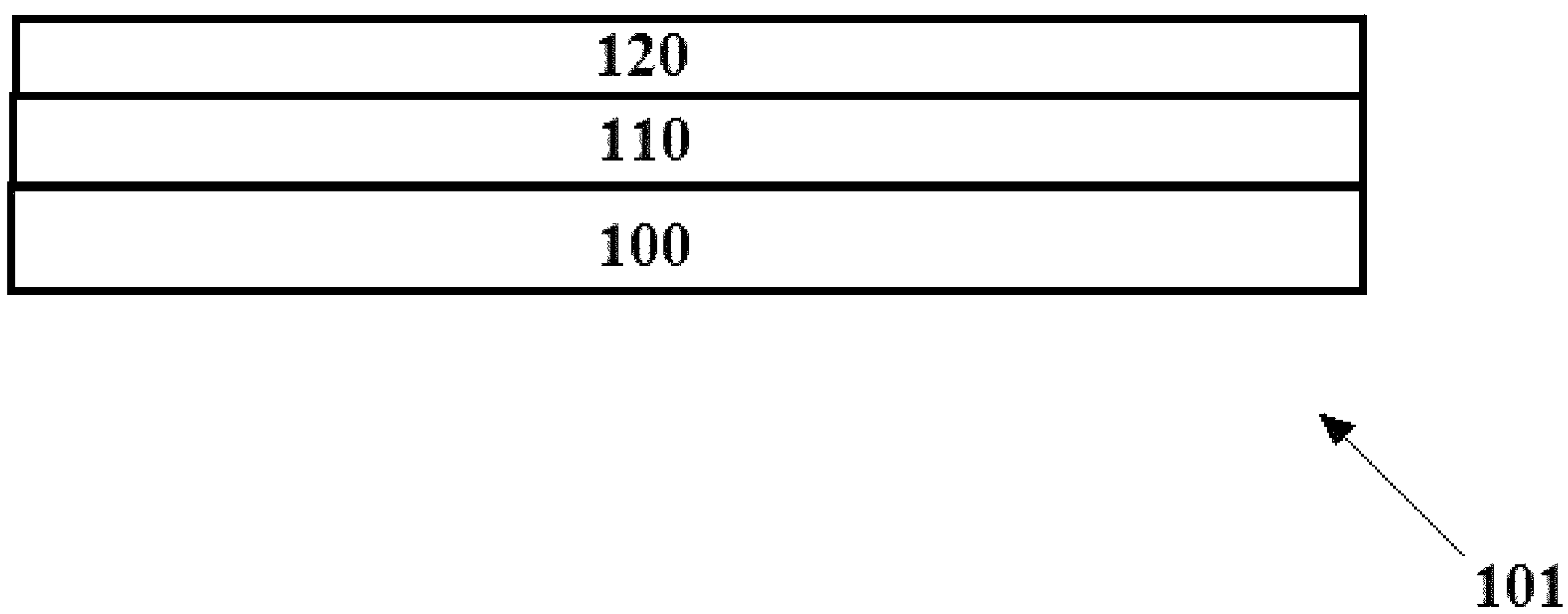


FIG.1

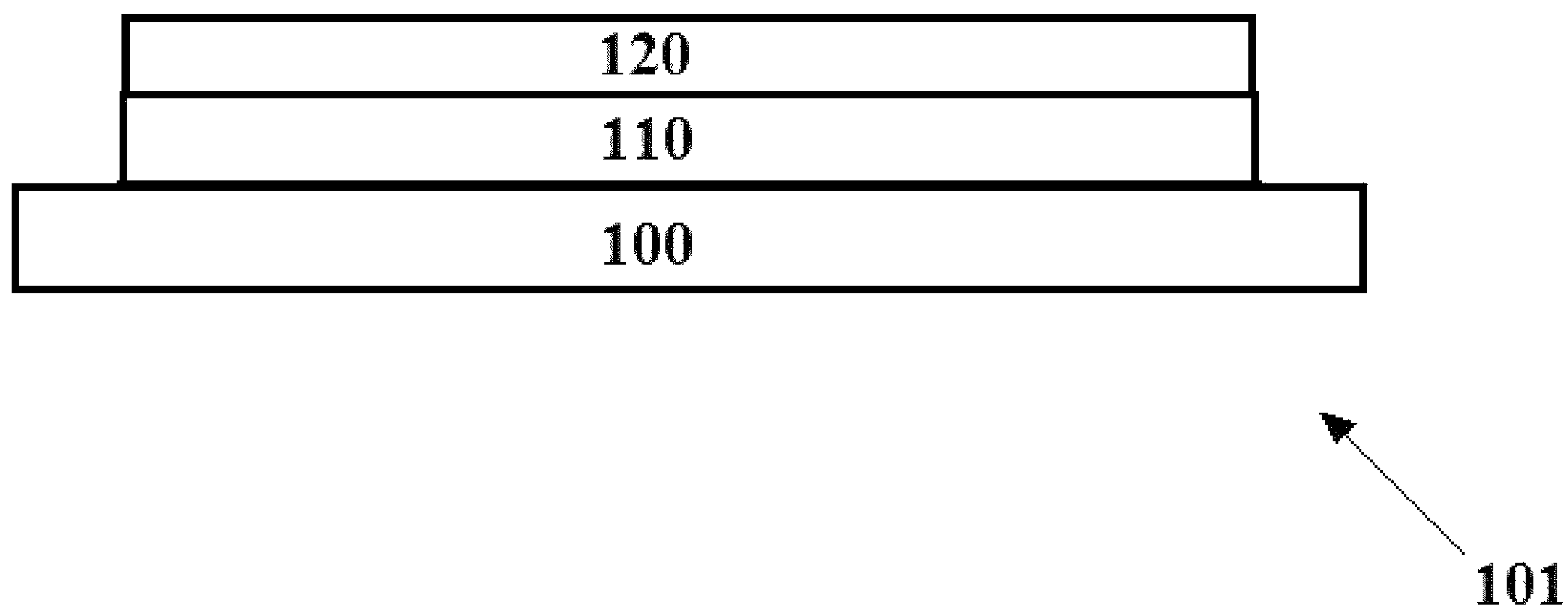


FIG.2

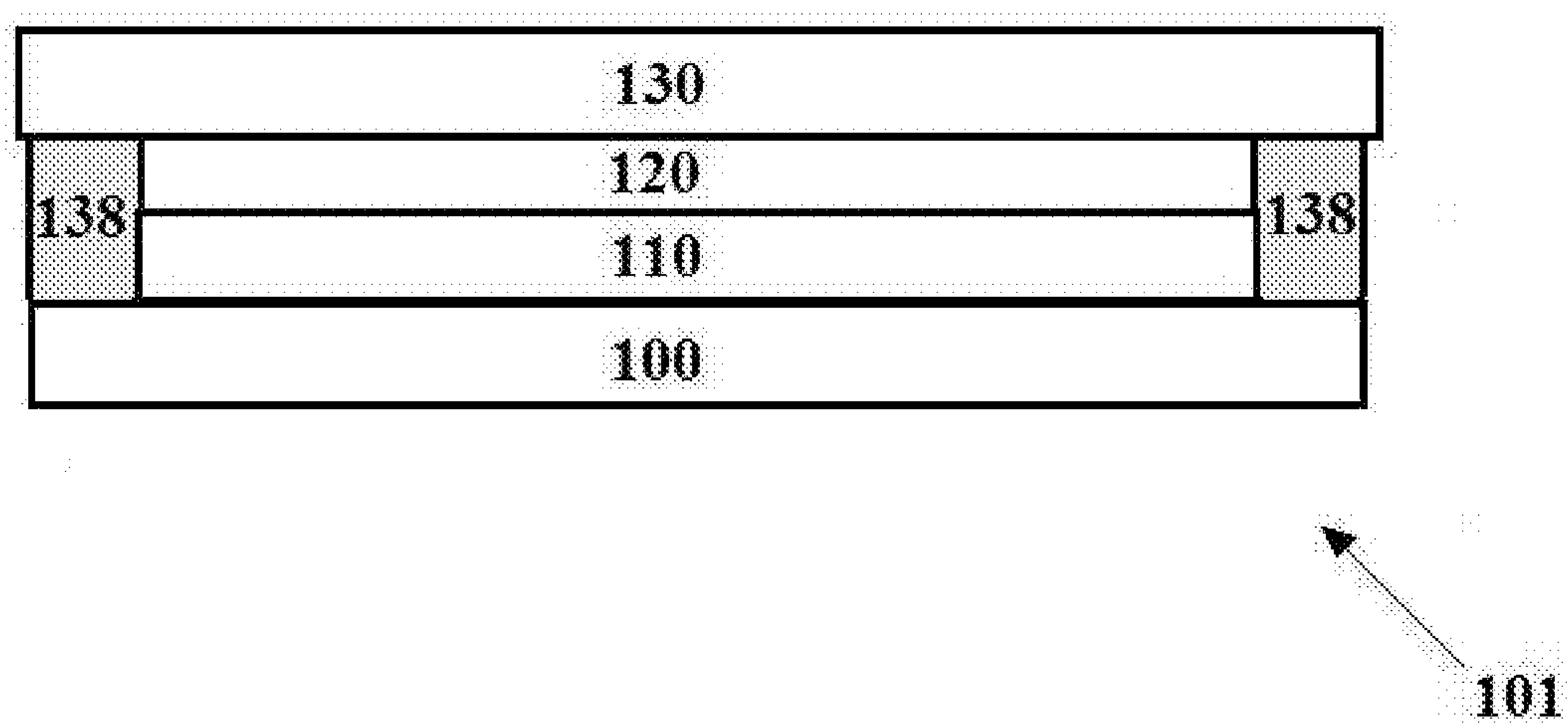


FIG.3

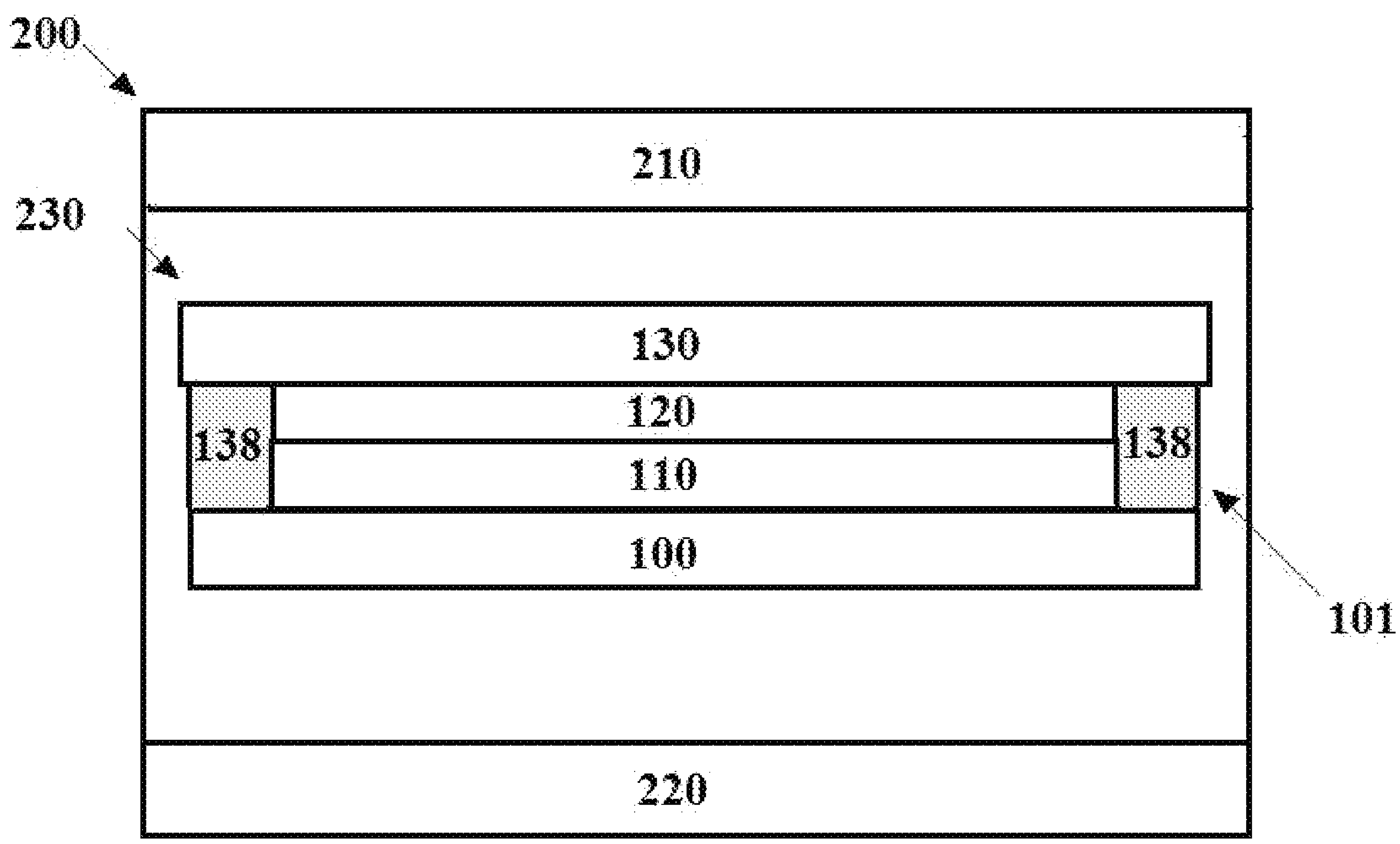


FIG.4

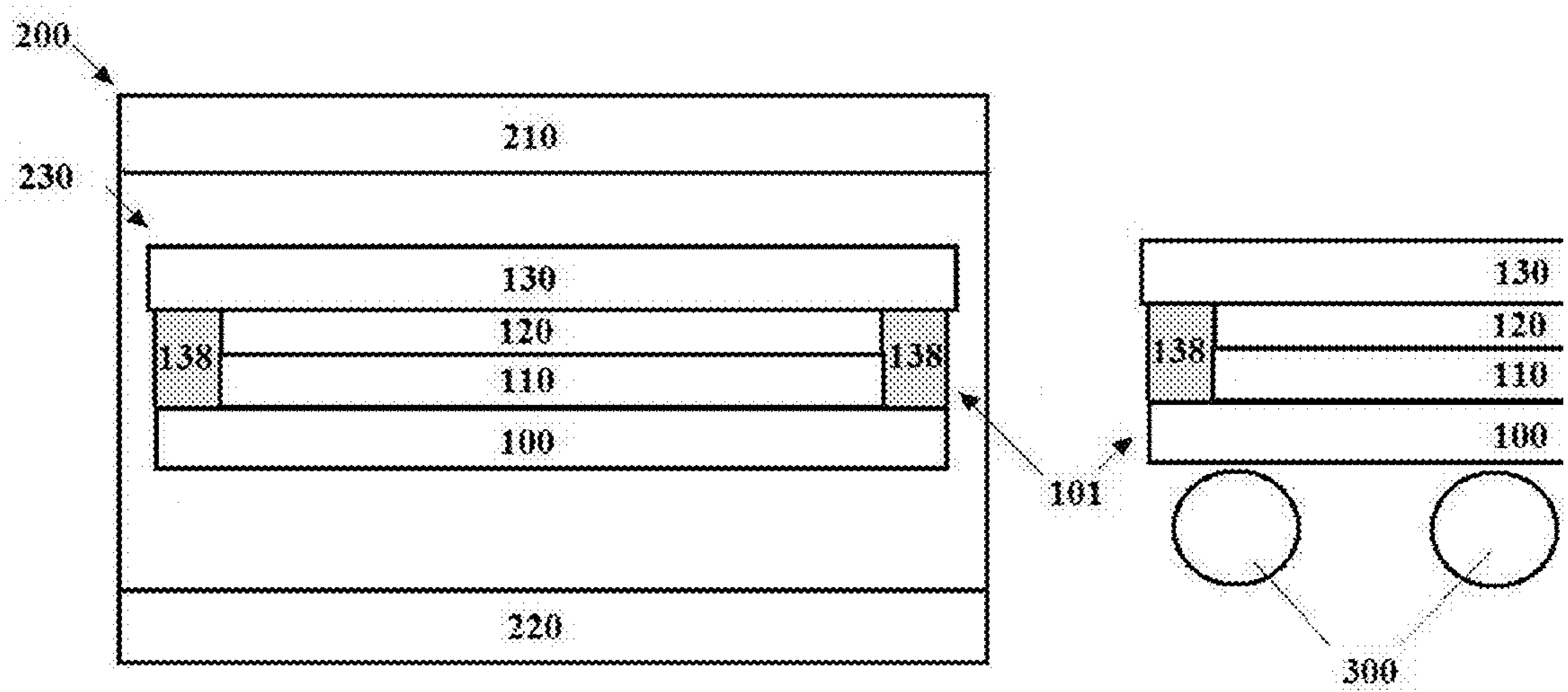

200
210
230
130
120
110
138
138
100
101
220
130
120
110
138
100
300

FIG.5

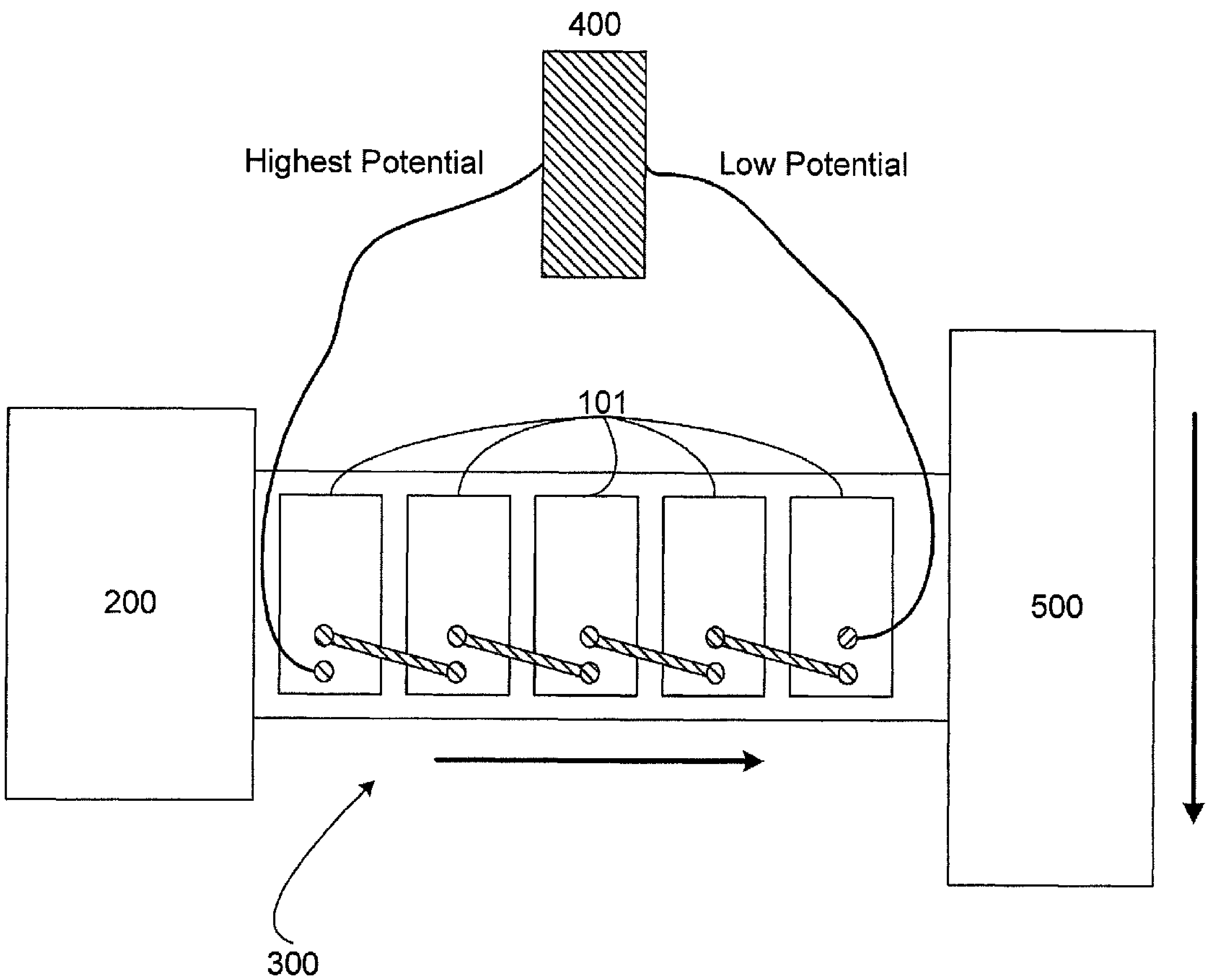


FIG. 6

PHOTOVOLTAIC MODULE MANUFACTURE

CLAIM OF PRIORITY

This application claims priority to U.S. Provisional Patent Application No. 61/309,064, filed on Mar. 1, 2010, which is incorporated by reference in its entirety.

TECHNICAL FIELD

The present invention relates to photovoltaic modules and methods of production.

BACKGROUND

Photovoltaic devices can include transparent thin films that are also conductors of electrical charge. Photovoltaic devices functionality can be based on the formation of a region high in electrons referred to as the n-type and a region high in holes concentration referred to as the p-type in intimate contact. Past photovoltaic devices can be reversibly or irreversibly affected by exposure to light during and after manufacture.

DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic of a photovoltaic module.

FIG. 2 is a schematic of a photovoltaic module.

FIG. 3 is a schematic of a photovoltaic module.

FIG. 4 is a schematic of a system for manufacturing a photovoltaic module.

FIG. 5 is a schematic of a system for manufacturing a photovoltaic module.

FIG. 6 is a schematic of a system for manufacturing a photovoltaic module.

DETAILED DESCRIPTION

Photovoltaic devices can include multiple layers formed on a substrate (or superstrate). For example, a photovoltaic device can include a barrier layer, a transparent conductive oxide (TCO) layer, a buffer layer, a semiconductor window layer, and a semiconductor absorber layer, formed in a stack on a substrate. Each layer may in turn include more than one layer or film. For example, the semiconductor window layer and semiconductor absorber layer together can be considered a semiconductor layer. The semiconductor layer can include a first film created (for example, formed or deposited) on the TCO layer and a second film created on the first film. Additionally, each layer can cover all or a portion of the device and/or all or a portion of the layer or substrate underlying the layer. For example, a "layer" can mean any amount of any material that contacts all or a portion of a surface.

Thin film solar cells such as those including copper-indium-gallium-selenium (CIGS), cadmium telluride (CdTe), and amorphous silicon (a-Si) often show changes in their current-voltage behavior after light exposures of extended periods of time (>0.5 hr-days). Some structures such as CIGS solar cells show transient degradation that is fully reversible. Some structures such as a-Si solar cells show degradation that is not reversible, often referred to as stabilization. In CdTe solar cells, both phenomena have been observed where efficiency increases and stabilizes or decreases after brief exposure to light. Currently, such reversible or irreversible changes create difficulties for the proper assessment of the relevant device performance as the device at the end of the manufacturing process may be in a state that is non-representative of the expected field performance. A manufacture process and the related system are developed as an alternative to using light exposure to invoke these changes in the device.

Thin film solar cells such as CIGS, CdTe, and a-Si often show changes in their current-voltage behavior after light exposures of extended periods of time (>0.5 hr-days). An increased temperature can accelerate these changes. Additionally, the application of an external electrical power supply that creates a bias in the photovoltaic device can be sufficient to induce these changes. The acceleration by temperature of the process by increasing the temperature during light exposure is tested. The same effect can be achieved under a constant current load while the device is held at an elevated temperature. Increasing the temperature while under a constant electrical current load can accelerate the change. These changes enable the process to become manufacturable. In some embodiments, this process can be combined with a lamination process, which has similar cycle times and can provide the heating required to invoke the necessary changes.

In a lamination process, thin film photovoltaic devices can be encapsulated within the module by materials designed to seal and hold the module together for many years and under a variety of conditions. The encapsulation material can help retain heavy metals present within the module by forming low solubility compounds that immobilize, chelate, adsorb, and/or fixate the cadmium and/or other heavy metals within the structure of the module to assist with handling and disposal.

In one aspect, a method for manufacturing a photovoltaic module can include heating a photovoltaic module to a temperature above 100 degrees C. and applying an electrical bias to the heated photovoltaic module. The step of heating the photovoltaic module occurs during a lamination process can include placing a photovoltaic module interlayer in contact with a photovoltaic module substrate before heating the photovoltaic module and pressing the interlayer and the substrate together. Applying an electrical bias to the photovoltaic module can take place after heating the photovoltaic module. Applying an electrical bias to the photovoltaic module can take place during heating of the photovoltaic module. Applying an electrical bias to the photovoltaic module can take place during the lamination process. Applying an electrical bias to the photovoltaic module can take place after the lamination process.

Applying an electrical bias can have a duration longer than that of heating the photovoltaic module. Applying an electrical bias can have a duration shorter than that of heating the photovoltaic module. Applying an electrical bias can have a duration substantially the same as that of heating the photovoltaic module. Applying the electrical bias can include supplying constant current with an upper voltage limit. Applying the electrical bias can include supplying constant voltage with an upper current limit. The electrical bias can generate a current that is in the range of 0.3-5 times of the short circuit current of the photovoltaic device.

Heating the photovoltaic module can include heating the photovoltaic module to a temperature in the range of 100 to 220 degree C. Heating the photovoltaic module can include heating the photovoltaic module to a temperature in the range of 120 to 180 degree C. Heating the photovoltaic module can include heating the photovoltaic module to a temperature in the range of 120 to 160 degree C. The lamination process can have a duration of 1 to 60 minutes. The lamination process can have a duration of 1 to 30 minutes. The lamination process can have a duration of 1 to 20 minutes. The lamination process can have a duration of 5 to 20 minutes.

The step of applying the electrical bias can include applying the electrical bias for 1 to 60 minutes. The step of applying the electrical bias can include applying the electrical bias for

1 to 20 minutes. The step of applying the electrical bias can include applying the electrical bias for 5 to 20 minutes.

In one aspect, a system for manufacturing a photovoltaic module can include a conditioning station including a heater configured to heat a photovoltaic module to a temperature greater than 100 degrees C. and a power source configured to apply an electrical bias to the photovoltaic module. The system can include a laminator configured to press a photovoltaic module interlayer and photovoltaic module substrate together after a photovoltaic module is heated. The system can include a conveyor to transport a photovoltaic module from the laminator.

The laminator can include the heater configured to heat a photovoltaic module to a temperature greater than 100 degrees C. and a press configured to force a photovoltaic module interlayer and a photovoltaic substrate together. The power source can be configured to apply the electrical bias to a photovoltaic module subsequent to the heater heating the photovoltaic module. The power source can be configured to apply the electrical bias to a photovoltaic device simultaneous to the heater heating the photovoltaic module. The power source can be set at a constant current with an upper voltage limit. The power source can be set at a constant voltage with an upper current limit.

The electrical bias can generate a current that is in the range of 0.3-5 times of the short circuit current of the photovoltaic device. The heater can be configured to heat a photovoltaic module to a temperature in the range of 120 to 180 degree C. The laminator can be configured to laminate a photovoltaic module for between 1 to 20 minutes. The system can include a photovoltaic module including a thin film photovoltaic device. The system can include a photovoltaic module including a cadmium telluride photovoltaic device. The system can include a photovoltaic module including a CIGS photovoltaic device. The system can include a photovoltaic module including an amorphous silicon photovoltaic device.

Referring to FIG. **1**, photovoltaic module **101** can include front substrate **100**. Front substrate **100** can include any suitable material, including glass, for example, soda-lime glass. One or more layers **110** can be deposited adjacent to front substrate **100**, which can serve as a first substrate, on top of which various layers may be added. Layer(s) **110** can include one or more device layers. For example, layer(s) **110** can include one or more thin film photovoltaic device layers. Photovoltaic device layers can further include a transparent conductive oxide layer adjacent to substrate **100**, a semiconductor window layer adjacent to the transparent conductive oxide layer, and a semiconductor absorber layer adjacent to the semiconductor window layer.

In some embodiments, layer(s) **110** can include cadmium telluride (CdTe) photovoltaic device layers. CdTe photovoltaic device layers can further include a transparent conductive oxide layer, a semiconductor window layer, and a CdTe absorber layer. In some embodiments, layer(s) **110** can include copper indium gallium selenide (CIGS) photovoltaic device layers. CIGS photovoltaic device layers can further include a transparent conductive oxide layer and a CIGS absorber layer. Layer(s) **110** can include any suitable photovoltaic absorber material, including, for example, silicon, such as amorphous silicon.

Layer (s) **110** can include additional metal layers adjacent to the semiconductor absorber layer. One or more metal immobilizing agents can be deposited adjacent to layer(s) **110**. For example, a metal immobilizing agent **120** can be deposited adjacent to layer(s) **110**.

Portions of semiconductor material and other coatings can be deleted from the edges of photovoltaic modules, which may comprise a series of connected photovoltaic devices. The semiconductor material can be removed from the edges by any suitable method. The area where the semiconductor material has been removed can be used to position, form, or deposit an interlayer material adjacent to the substrate. Referring to FIG. **2**, portions of layer(s) **110** and layer(s) **120** have been removed from photovoltaic device **101** by mechanical means that can include laser scribing.

Referring to FIG. **3**, photovoltaic module **101** can include one or more interlayers **138**, in contact with layer(s) **110** and layer(s) **120**. A photovoltaic module **101** can also include a back substrate **130**. Back substrate **130** can include any suitable material, including glass, for example, soda-lime glass. Back substrate **130** can be added to photovoltaic module **101** after the addition of interlayers **138**. Alternatively, back substrate **130** can be added to photovoltaic module **101** before interlayers **138** are added. For example, back substrate **130** can be positioned adjacent to layer(s) **110** and layer(s) **120** to form a space proximate to the edge portions of front substrate **100** and back substrate **130**. Interlayer material can be positioned in this space to form interlayer **138**.

The layers of photovoltaic module **101** can be aligned, heated, and bonded together by a lamination process. Lamination encapsulates the semiconductor layers, TCO, metal conductor, and any other layers of photovoltaic module **101**, sealing the photovoltaic devices from the environment. The front substrate **100** and the back substrate **130** can be bonded together with interlayers **138** through a lamination process. The interlayers can include a thermoplastic interlayer. The thermoplastic interlayer can include an acrylonitrile butadiene styrene (ABS), an acrylic (PMMA), a celluloid, a cellulose acetate, a cycloolefin copolymer (COC), a polyvinyl butyral (PVB), a silicone, an epoxy, an ethylene-vinyl acetate (EVA), an ethylene vinyl alcohol (EVOH), a fluoroplastic (PTFE), an ionomer, KYDEX®, a liquid crystal polymer (LCP), a polyacetal (POM), a polyacrylate, a polyacrylonitrile (PAN), a polyamide (PA), a polyamide-imide (PAI), a polyaryletherketone (PAEK), a polybutadiene (PBD), a polybutylene (PB), a polybutylene terephthalate (PBT), a polycaprolactone (PCL), a polychlorotrifluoroethylene (PCTFE), a polyethylene terephthalate (PET), a polycyclohexylene dimethylene terephthalate (PCT), a polycarbonate (PC), a polyhydroxyalkanoate (PHA), a polyketone (PK), a polyester, polyethylene (PE), a polyetheretherketone (PEEK), a polyetherketoneketone (PEKK), a polyetherimide (PEI), a polyethersulfone (PES), a polyethylenechlorinate (PEC), a polyimide (PI), a polylactic acid (PLA), a polymethylpentene (PMP), a polyphenylene oxide (PPO), a polyphenylene sulfide (PPS), a polyphthalamide (PPA), a polypropylene (PP), a polystyrene (PS), a polysulfone (PSU), a polytrimethylene terephthalate (PTT), a polyurethane (PU), a polyvinyl acetate (PVA), a polyvinyl chloride (PVC), a polyvinylidene chloride (PVDC), or a styrene-acrylonitrile (SAN), or any other suitable material, or any combination thereof. In certain embodiments, thermoplastic interlayer can include an ethylene vinyl acetate (EVA), a polyvinyl butyral (PVB), a silicone, or an epoxy.

Referring to FIG. **4**, front substrate **100**, back substrate **130** and interlayer **138** of photovoltaic module **101** can be pressed together. The means of pressing front substrate **100**, back substrate **130** and interlayer **138** can include laminator **200**, which can include a press. Laminator **200** can treat photovoltaic module **101** in lamination chamber **230** by heating from the bottom heating plate **220** of laminator **200** that is facing back substrate **130** while the top and bottom plates **210** and **220** of laminator **200** press front substrate **100** and back substrate **130** together. Interlayer **138** can be melted, allowed to flow and fill in gaps, and cured by this process. Lamination chamber **230** can be a vacuum chamber.

In some embodiments, photovoltaic module **101** can be heated with a source of infrared radiation (IR) in addition to treatment in laminator **200** in the lamination process. An IR heater can be used before or after interlayer **138** is added to photovoltaic device **101**.

Referring to FIGS. **5** and **6**, a system of manufacturing a photovoltaic module can include laminator **200** to laminate photovoltaic module **101**, conditioning station **300** to condition module **101** after laminator **200**, and power source **400** to apply an electrical bias to photovoltaic module **101**. In some embodiments, as shown in FIG. **6**, power source **400** can be configured to apply an electrical bias to photovoltaic module **101** on conditioning station **300**. The system of manufacturing a photovoltaic module can include conveyor **500**. Conditioning station **300** can be configured to condition photovoltaic module **101** between laminator **200** and conveyor **500**.

In some embodiments, the system can execute lamination and conditioning (e.g., heating and biasing of the photovoltaic module) in the same temperature cycle. Typical lamination temperature is in the range of 120-180 degree C. for a time period of 5-20 minutes. In this system, the electrical bias can be provided through an electrical power supply that is set at a constant current with an upper voltage limit or at a constant voltage with an upper current limit during the temperature cycle. The current can be in the range of 0.3-5 times the short circuit current of the photovoltaic device. The current can be in the range of 0.3-3 times the short circuit current of the photovoltaic device. In some embodiments, the system can provide lamination of the packaging and a conditioning of the photovoltaic module during a single temperature cycle through the application of an electrical bias during the temperature cycle of the lamination.

In some embodiments, the process of conditioning can occur through the application of electrical bias and heat after lamination. Indirect heat may be partially or completely provided by the lamination cycle. Typical module temperatures upon exit from lamination tool **200** can be 120-160 degree C. and the bias can be applied while the temperature is maintained or ramped down from lamination temperatures. Process times can be in the range of 1-20 minutes.

In some embodiments, the system can provide lamination of the packaging and a conditioning of the semiconductor after completion of the lamination cycle. The conditioning process can maintain cycle time of the lamination tool and the modules can remain stationary after exit from lamination tool **200** during the process. No secondary heat source is required.

Applying an electrical bias to the photovoltaic device can take place before, after, or during heating of the lamination cycle. The length of applying an electrical bias to the photovoltaic device can be longer or shorter than that of heating of the lamination cycle. Applying an electrical bias to the photovoltaic device can have the same length of time as heating of the lamination cycle.

As shown in FIG. **6**, a system for manufacturing a photovoltaic module can include laminator **200**, conditioning station **300**, power source **400**, and conveyor **500**. Laminator **200** can include a heater to heat a photovoltaic module and a press to laminate a photovoltaic module, for example, by pressing a photovoltaic module interlayer together with a photovoltaic module substrate. The heated photovoltaic module can be positioned in conditioning station **300**, which can provides electrical contacting and biasing. Modules can be held in conditioning station **300** after completion of the lamination cycle by laminator **200**. Laminator **200** can start the lamination cycle on the next photovoltaic module **101**.

During the manufacture of a photovoltaic module, electrical contact pads can be applied to photovoltaic module **101** that place the modules either in parallel or serial connection. Power source **400** can be used to operate the modules in constant current or constant voltage mode. A typical process window can be a current in the range of 0.3-5 times (for example, 0.3-3 times) the short circuit current of the photovoltaic device and a processing time of application shorter than the lamination cycle. During this time photovoltaic module **101** can be actively heated, cooled, or simply exposed to ambient to achieve a desirable temperature profile. When modules of a previous photovoltaic module batch clear conditioning station **300**, the lamination cycle completes on the next photovoltaic module batch and the next batch can enter conveyor **500** located next to conditioning station **300**.

As described above, conditioning of the photovoltaic modules by applying an electrical bias can occur while the photovoltaic module is being heated, or after the photovoltaic module has been heated. The conditioning can occur during the lamination process or after the lamination process. The photovoltaic module can be laminated, which can include heating the photovoltaic module. The heated photovoltaic module can then be conditioned by applying an electrical bias, after the photovoltaic module has been heated and while it is cooling. The photovoltaic device processed by the new method and system can have about a 5-20 percent efficiency increase compared to unconditioned photovoltaic modules, for example about a 15 percent improvement in efficiency. In some embodiments, the new method of manufacturing a photovoltaic device can achieve a reduction in the cost and time of production.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. It should also be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various preferred features illustrative of the basic principles of the invention.

What is claimed is:

1. A method for manufacturing a photovoltaic module comprising:

heating a photovoltaic module to a temperature above 100 degrees C.; and

applying an electrical bias to the heated photovoltaic module,

wherein the step of heating the photovoltaic module occurs during a lamination process further comprising:

placing a photovoltaic module interlayer in contact with a photovoltaic module substrate before heating the photovoltaic module; and

pressing the interlayer and the substrate together.

2. The method of claim **1**, wherein applying an electrical bias to the photovoltaic module takes place during the lamination process.

3. The method of claim **1**, wherein applying an electrical bias to the photovoltaic module takes place after the lamination process.

4. The method of claim **1**, wherein the lamination process has a duration of 1 to 60 minutes.

5. A method for manufacturing a photovoltaic module comprising:

heating a photovoltaic module to a temperature above 100 degrees C.; and

applying an electrical bias to the heated photovoltaic module, wherein applying an electrical bias to the photovoltaic module takes place after heating the photovoltaic module.

6. The method of claim **5**, wherein applying an electrical bias has a duration substantially the same as that of heating the photovoltaic module.

7. The method of claim **5**, wherein applying the electrical bias includes supplying constant current.

8. The method of claim **5**, wherein applying the electrical bias includes supplying constant voltage.

9. The method of claim **5**, wherein the electrical bias generates a current that is in the range of 0.3-5 times of the short circuit current of the photovoltaic device.

10. The method of claim **5**, wherein heating the photovoltaic module comprises heating the photovoltaic module to a temperature in the range of 100 to 220 degree C.

11. The method of claim **5**, wherein the step of applying the electrical bias comprises applying the electrical bias for 1 to 60 minutes.

12. A method for manufacturing a photovoltaic module comprising:

heating a photovoltaic module to a temperature above 100 degrees C.; and

applying an electrical bias to the heated photovoltaic module,

wherein applying an electrical bias has a duration longer or shorter than that of heating the photovoltaic module.

13. A system for manufacturing a photovoltaic module comprising:

a conditioning station including a heater configured to heat a photovoltaic module to a temperature greater than 100 degrees C.;

a power source configured to apply an electrical bias to the photovoltaic module;

a laminator configured to press a photovoltaic module interlayer and photovoltaic module substrate together after a photovoltaic module is heated; and

a conveyor to transport a photovoltaic module from the laminator.

14. The system of claim **13**, wherein the power source is configured to apply the electrical bias to a photovoltaic module subsequent to the heater heating the photovoltaic module or is configured to apply the electrical bias to a photovoltaic device simultaneous to the heater heating the photovoltaic module.

15. The system of claim **13**, wherein the power source is set at a constant current or is set at a constant voltage.

16. The system of claim **13**, further comprising a photovoltaic module including one or more of thin film photovoltaic device, cadmium telluride photovoltaic device, CIGS photovoltaic device, or amorphous silicon photovoltaic device.

17. The system of claim **13**, wherein the interlayer comprises a thermoplastic material.

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